SPECIAL HANDLING, WATER MANAGEMENT, AND ALKALINE ADDITION TECHNIQUES: CASE STUDIES FROM PENNSYLVANIA

Eric F. Perry[(1)]
Michael D. Gardner[(2)]
Robert S. Evans[(1)]

(1) US Office of Surface Mining, 3 Parkway Center, Pittsburgh, Pa. 15220.

(2) Pennsylvania Department of Environmental Protection, RR2 Box 603, Greensburg, Pa. 15601.

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INTRODUCTION

Acid drainage and acid mine spoils in northern Appalachia are a byproduct of over one hundred years of extensive surface and underground coal mining. Current surface mining technology for handling materials to prevent acid drainage are of four general types:

- "Special handling"; controlled placement of material in designated zones in a mine backfill, usually above the expected postmining water table,
- Water management; routing surface and ground water, usually away from acid materials,
- Alkaline addition; introducing limestone or other bases to amend deficiencies or supplement neutralizers on site,
- Chemical and biological controls; targeting specific steps of the acid generation cycle, such as bactericides.

In this paper, we report on the application of special handling, water management, alkaline addition, and operating practices, and the resulting post mining drainage quality at six Pennsylvania surface coal mines. Mining methods consisted of block cut or area mining, with truck and loader or small draglines used for spoil handling. Most coal operations with acid drainage potential use special handling, water management, alkaline addition, and/or operational considerations in combination to prevent the formation of acid mine drainage (AMD). Early guidelines for AMD prevention on surface mines were established in 1952 by the Pennsylvania Sanitary Water Board. "Control of Acid Drainage from Coal Mines", required placement of acidic material near the outcrop and on the pit floor buried beneath a spoil ridge. Burial was thought to exclude oxygen from contacting acid forming material. Highwall diversion ditches, pit floor drains, contemporaneous backfilling, and grading topography to limit infiltration were also recommended.

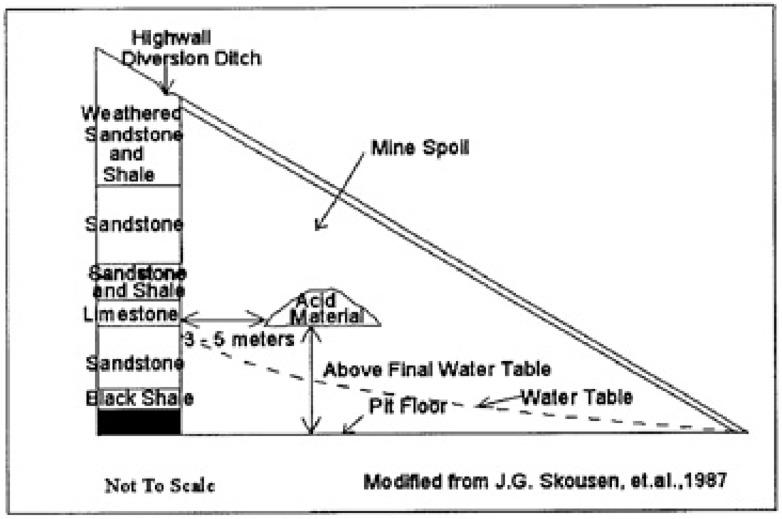

Figure 1 Dry Disposal of Acid Material

The Surface Mine Drainage Task Force (1979) published a set of guidelines for special handling acid minespoil in West Virginia. This group emphasized "dry" placement above the expected water table in the spoil backfill. Key recommendations included routing surface and ground water away from acid material, and controlled placement of minespoil. Controlled placement included a pad of 4 feet of non-acid, free draining waste rock on which acid material was placed. In addition, the acid materials were placed away from the final highwall/mine spoil interface. A 10 to 20 feet thick free-draining zone of non-acid material was recommended to route water through the reclaimed backfill. Other options presented included blending with excess calcareous rock, liming or sealing the pit floor, and maintaining positive drainage. The importance of maintaining an equipment spread capable of selective placement and the added material handling costs were also recognized and discussed. A generalized illustration of special handling and placement above the water table is shown in figure 1. Placement above the water table remains the principal approach used in Appalachia at present. The Surface Mine Drainage Task Force guidelines were later updated (Skousen et.al, 1987) to incorporate additional studies on minespoil hydrology, capping and alkaline recharge. These updated guidelines also recommended dry disposal above the pit floor, with neutralization, compaction and covering to minimize oxygen and water contact.

METHODS

Six Pennsylvania surface mine sites that used special handling, water management, alkaline addition, or special operating techniques, alone or in combination were evaluated. Our approach was to examine the effects of mining and reclamation practices on post mining water quality, separate and apart from geologic and hydrologic controls. Each mine contained strata capable of producing acid drainage and had been mined, backfilled and revegetated. A chronology of mining activities was compiled including mining method, problems encountered, revisions to mine plan, alkaline addition, unanticipated events and conditions, delays in backfilling and reclamation, and documentation of special handling activities.

Geochemical and lithologic properties were determined from drill logs and Acid/Base Accounting (ABA) analyses (Sobek et.al., 1978) for Maximum Potential Acidity (MPA), Neutralization Potential (NP), and Net Neutralization Potential (NNP). Two to five drillholes were analyzed per site. ABA data were summarized using volume weighting techniques described by Smith and Brady (1990). "Areas of influence" were assigned to each drillhole and summary numbers weighted according to the thickness, density and areal extent of each strata. Data from each hole were combined to obtain a weighted average **MPA, NP and NNP** for each mine.

The mine summary data were compared to postmining predictive criteria for net alkalinity and ABA that we determined in previous studies in Pennsylvania (Brady et al, 1994; Perry and Brady, 1995). Those findings are shown in table 1, and include three water quality categories; net acid, variable and net alkaline. About 80 percent of mines with NP less than 10 tons/1000 or NNP less than zero produced net acid water. All mines with NP greater than 21 tons/1000 or NNP greater than 12 tons/1000 produced net alkaline drainage, while the "variable" category included both acid and alkaline waters.

Table 1
Postmining Net Alkalinity vs.
Neutralization Potential and Net Neutralization Potential
(From Brady et.al, 1994 and Perry and Brady, 1995)

Overburden Quality	Water Quality		
	Net Acid	Variable	Net Alkaline
Neutralization Potential (NP)	<10 ton/1000	10 to 21 ton/1000	>21 ton/1000
Net Neutralization Potential (NNP)	<0 ton/1000	0 to 12 ton/1000	>12 ton/1000

Ground water quality data were evaluated using non-parametric statistics as recommended by Helsel (1987). Acidity, alkalinity, pH, sulfate, and metals of all discharges were reviewed; however most results reported here are for a single representative discharge. Unless otherwise noted, the reported data are median values. The period of postmining record ranged from two to six years.

Based only on the ABA criteria in table 1, expected water quality was categorized, and then compared to actual mine drainage chemistry. The expected postmining water quality (table 2), is the prediction that would be made considering Acid Base Accounting only, without regard to effects of special handling or hydrologic conditions. The differences between expected and actual chemistry were examined as possible results of special handling and other preventive practices. Summary overburden data, their expected and actual post mining water quality, and special handling practices, are shown in table 2.

Table 2
Special Handling Practices, Summary Overburden Quality,
Expected and Actual Postmining Water Quality for Six Surface Coal Mines

Mine Identification/ Special Handling Practice	Neutralization Potential (NP,t/1000t)	Net Neutralization Potential (NNP,t/1000t)	Predicted Postmining Water Quality	Actual Postmining Water Quality
Schott Mine/ Alkaline Redistribution and "Dry" Placement	15.32	4.58	Variable; could be acid or alkaline	Alkaline.low metals
Greene Phase 1/ Alkaline addition and "Dry" Placement	14.14	10.61	Variable, could be acid or alkaline	Alkaline, low metals
Greene Phase II/ Alkaline Addition and "Dry" Placement	20.94	5.55	Variable, could be acid or alkaline	Acid, high metals
Rapchak Mine/ Alkaline Addition, "Dry Placement", Clay Cap, Highwall Drain	5.35	-9.56	Net Acid	Alkaline, low metals
Highwoods Mine/ "Dry" Placement, Pit Floor Drains, Alkaline Addition	3.96	-0.23	Net Acid	Alkaline, low metals
Spaw Mine, "Dry" Placement	51.7	45.7	Net Alkaline	Acid, some metals

RESULTS AND DISCUSSION

Special Handling and Operating Techniques

All six mines used utilized some type of special handling scheme that included placement of acid or calcareous material in targeted zones of a mine backfill. Each mine attempted placement of acid material above the expected postmining water table. Various degrees of capping and compaction were sometimes included as part of special handling and placement. Alkaline redistribution of calcareous material on site was the major special handling activity at one mine. The intent of special handling acid materials at all sites was to exclude water or oxygen from contact with sulfide minerals, and minimize acid production and leaching of add products. Calcareous material was placed so as to be in the expected groundwater flow path, to dissolve and produce alkalinity. Special handling activities and effects are exemplified by the following mines:

Greene Co Phase 1 and 2: These special handling sites were mined by the same company, using truck and loaders and block cut methods, on two adjacent but hydrologically separate tracts. Acid Base Accounting, stratigraphy and structure on the two tracts were similar. On both phases, about from two to ten feet of potentially acid shale, located just above the Waynesburg coal, was designated for special handling and "dry" placement. Mining, backfilling and reclamation on Phase 1 was completed without work stoppage between 1985 and 1989. Periodic inspection showed that the special handling plan was followed. Mining and reclamation of Phase 2 occurred between 1988 and 1992, but the mine was inactive or in "temporary cessation" for about a two and a half year period. During this cessation, reclamation was only partially complete and some acidic spoil material was exposed. Inspection of the operation revealed that the special handling plan was not followed diligently, and some acid shale was placed near the base of the backfill at or near the zone of ground water saturation.

Table 3
Summary Water Quality for Greene Phases 1 and 2

Monitoring Point	pH S.U.	Net Alkalinity (mg/l $CaCO_3$ Eq)	T. Iron (mg/l)	T. Manganese (mg/l)	Sulfate (mg/l)
Phase 1, Mining	6.5	176	0.3	8.1	606
Phase 2, Mining	3.6	-488	71.4	105	2233
Phase 1, Postmining	7.2	144	1.97	15.4	1194
Phase 2, Postmining	4.5	-147	26.7	62.7	1788

No acidic drainage has been found on the phase 1 tract (table 3). Alkaline groundwater, containing elevated sulfates and some manganese is present in two monitoring wells and two seeps on phase 1. Acid seeps began to discharge from the toe of spoil on Phase 2 before mining was completed. Water quality in Phase 2 was substantially poorer both during and after mining. The acid seeps had significantly higher concentrations of iron and sulfate. Backfilling and reclamation of Phase 2 improved postmining water quality. Median acidity declined from 488 to 147 mg/l $CaCO_3$ with corresponding decrease in metals and sulfate concentrations. Two newly installed wells on Phase II show variable water quality in the spoil, depending on acid material placement within the tract. Sulfate concentration increased after reclamation in Phase 1, but has remained stable for more than five years of post mine monitoring.

The principal differences between the two phases are poor special handling and extended cessation of operations on Phase 2. Phase 1 was operated with no work stoppages, and placement of special handled shale in the backfill occurred as planned. Phase II included a "temporary cessation" of about two years before mining and reclamation were concluded, exposing the shale to weathering and acid generation. Special handling of the acid shale was less controlled, and some material was placed low in the backfill in the ground water flowpath. Based on the similar overburden quality and hydrologic conditions on the two tracts, mine drainage quality should have been comparable.

Schott Mine: This site featured special handling of both alkaline and acid material. Calcareous material was present only in a few acres at the updip end of the site, and was absent or thin elsewhere. The operator special handled (redistributed) alkaline materials from sections of excess to alkaline deficient areas. To accomplish this redistribution plan, three pits were operated simultaneously using the block cut method. One pit was in the excess alkaline area; the others in the alkaline deficient area. Coal removal and overburden handling was done with a combination of trucks, loaders and dozers. Operations were timed so that alkaline material was available for haulage and placement and cut and fill material balances could be maintained. This site had marginal ABA qualities (table 1) and some subareas within the mine were potential acid generators without the redistribution plan.

Two zones of potentially acid forming shales were identified in the interburden; about 20 feet above the lower coal (Upper Kittanning) and about 10 feet below the Lower Freeport coal. Underclay materials were also found to be potentially acid forming. The operator special handled the shales and pit cleanings for placement above the water table and interlayed them with alkaline spoil.

Mining progressed rapidly, with the entire operation completed in about six months. Periodic inspection during mining and reclamation found the special handling plan to have been implemented as proposed.

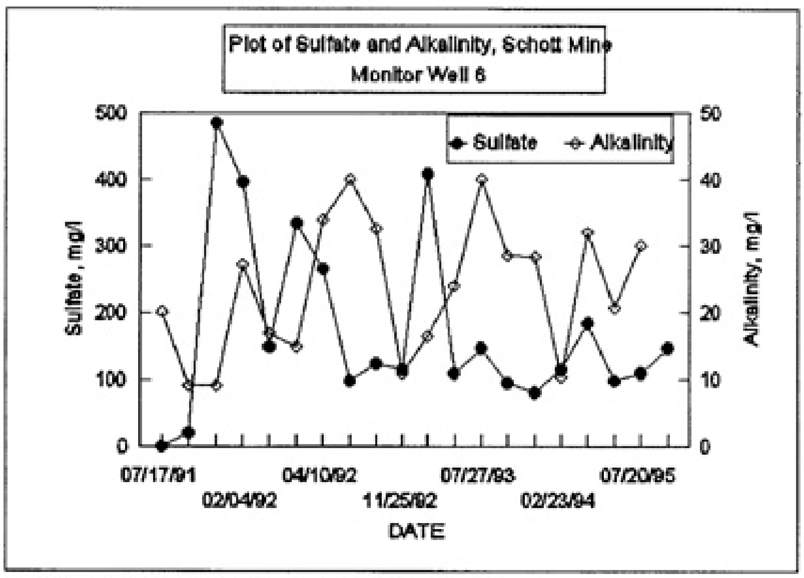

Figure 2,Groundwater Quality, Schott Mine

Groundwater quality has been monitored for over 5 years at monitoring well MW- 6 (figure 2). The well was *completely* dewatered for about 4 months during active mining in the recharge area for the well. After mining and backfilling were complete, a saturated zone was reestablished. It ranges in thickness from about 5 to 20 feet and exhibits seasonal variation. Plots of sulfate and alkalinity show a peak in sulfate concentration as mining was completed and a water table reestablished. Almost immediately however, sulfate levels began to decline. Net alkaline water has been recorded in this well since immediately after mining. Median iron and manganese concentrations are 1.6 and 0.3 mg/l respectively for the postmining period. The key factors influencing postmining water quality are the redistribution of calcareous rock to alkaline deficient areas, and rapid completion of mining and reclamation. Mining and backfilling of this site was completed in about six months time, without work stoppage or prolonged exposure of acid forming materials. We attribute the responses in water chemistry to placement of materials as specified in the mining plan and verified during site inspections. Acid forming materials are above the water table to minimize leaching, and the calcareous rocks are dissolving and producing alkalinity.

Two factors: timeliness of mining and backfilling, and controlled placement of acidic material above the water table influence water chemistry at other study sites as well. The Spaw mine experienced significant delays of six months or more before final backfilling. Mining was conducted with a small dragline resulting in poor control of acid material placement of some areas of the mine. Acid groundwater began seeping from the site within a year of reclamation.

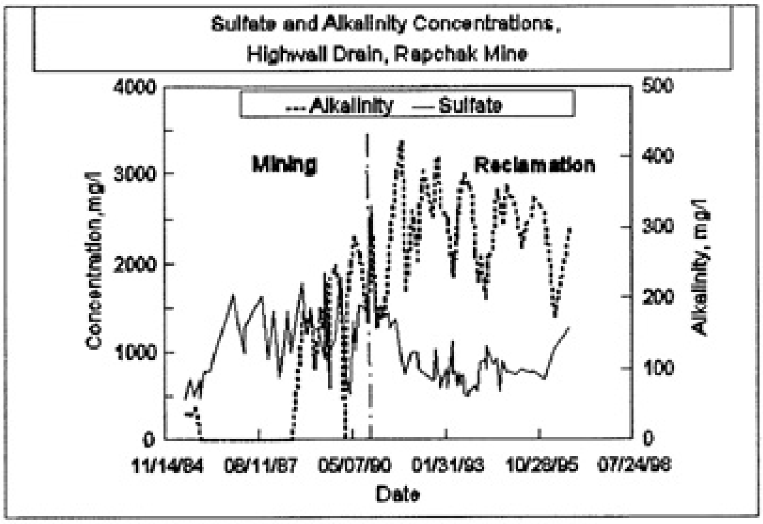

Figure 3 Rapchak Mine Highwall Drain Quality

The Rapchak site, also mined with a small dragline, had only one pit open when the company temporarily ceased coal loading. Unreclaimed shale began to produce low volume very acidic seepage during cessation from late 1985 to 1988. A modified reclamation plan was implemented that included special handling and "dry" placement of acid shale. Special handling, in conjunction with hydrologic routing and alkaline addition ultimately produced alkaline drainage. Figure 3 is a plot of sulfate and alkalinity concentrations for the principal discharge at the Rapchak site. As backfilling and reclamation was completed in 1991, sulfate concentration rapidly decreased by about one third, and alkalinity increased.

Other mines in this study were mined and reclaimed rapidly and without stoppage, including Schott and Highwoods. In general, these mines experienced fewer water quality problems than sites with long delays in backfilling or poor control of material placement.

Water Management

Water management can include pit floor drains and highwall diversions to route ground water through backfills, reduce infiltration, and minimize contact with acid material (Gardner, 1998). This technology has been used on a number of Pennsylvania surface mines. Liners or caps, constructed of low permeability soil, spoil or synthetic materials have been used on a few surface coal mines to restrict infiltration and oxygen flow into pyritic material. Two mines, Highwoods and Rapchak used drains and capping to manage acid materials.

Highwoods:

The Highwoods mine contained potentially acid underclays and pit cleanings, and was mined with trucks and loaders. It is located on an isolated ridgetop on a structural dip of about 9%. Mining proceeded downdip, ending at a final highwall height of 50 feet. Ground water recharge is mostly from precipitation falling directly on the mine. The combination of limited recharge and significant dip provided conditions suited to pit floor drains. Ground water was to be controlled by placing pit floor drains in the backfill at intervals of about 600 feet. The drains are expected to intercept and discharge spoil ground water and prevent development of a thick ground water table within the backfill.

Installation procedures for drains included several considerations; construction method, selecting appropriate material (i.e. pipe or rock), and insuring that the drain was not crushed during backfilling. Before laying the drain, an inert clay barrier was placed on the acid underclay. This permitted groundwater flow along the top of the inert clay rather than on the acidic underclays. Perforated flexible pipe was laid along the low side of each pit. The pipe was covered with crushed limestone to a depth of approximately 2 feet using a backhoe or small front end loader to prevent compressing or crushing the pipe. Subsequent backfilling was conducted using normal techniques. Pipes were extended to the coal cropline, where they discharge into a collection ditch. Air traps were installed on several drains to prevent oxidation and precipitation of iron in the pipe.

This same mining company has also installed drains by excavation of a small channel in the pit floor with suitable mining equipment to a depth just sufficient (about 1 foot) to capture groundwater. A pipe is placed in the bottom and covered with gravel or coarse grained material. Finally, to prevent infiltration of sediment which could plug the pipe, filter fabric is installed over the ditch.

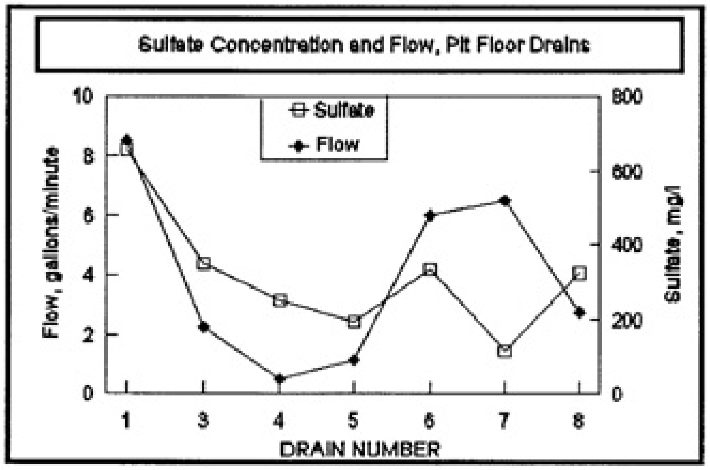

Figure 4 Highwoods Mine, Drains Discharge and Quality

The Highwoods drains have collected and discharged groundwater for two and half years after final backfilling. Median discharge and sulfate concentrations for the seven drains are shown in figure 4. The drains collectively discharge about 26 gallons per minute from an estimated recharge area of 100 acres, with the drainage area about equally divided among the seven pipes. Discharge is not uniformly partitioned among the drains however, with lowest flows from drains 3, 4, and 5 in the middle of the site. The largest discharges are from drain 1 downdip and near the final highwall, and drains 6 and 7 at the upper end of the site. Water table thickness measured in several spoil monitoring wells ranges from about 2 feet near drain 1 to about 7 feet near drain 4.

Median water quality for the seven drains is summarized in table 4. General groundwater flow direction is from drain 8 towards drain 1. As would be expected, metals and sulfate concentrations are greater down the flowpath at drains 1 and 3. All drains have net alkaline water for the monitoring period. However, the most recent three months of monitoring show increasing acidity and sulfate concentrations at drain 1, and there is concern that the clay barrier over the acid underclay may be leaking. This would allow ground water to migrate on to the acid underclay.

Table 4
Median Water Quality of Pit Floor Drains After Reclamation, Highwoods Mine

Drain #	pH (SU)	Net Alkalinity (mg/l CaCO3 Eq.)	T. Iron (mg/l)	T. Manganese (mg/l)	Sulfate (mg/l)
1	6.0	119	16.4	26.4	656
3	6.2	260	44.3	15	352
4	6.4	102	3.3	10.4	253
5	6.2	160	2.9	10.7	195
6	6.3	264	3.3	14.5	332
7	6.1	198	8.5	9.9	115
8	6.3	186	8.3	19.1	307

The pit floor drains serve to control and direct ground water discharge from this site. If these controls were not in place, ground water flow would mound against the downdip highwall and eventually discharge as a large seep zone along the base of the fill. No such seeps exist on this mine.

Rapchak:

This mine included the construction of a combination highwall/pit floor drain to intercept and route ground water inflow through the fill, and construction of a clay cap at the spoil surface. Mining was conducted with a small dragline between 1985 to 1991, and included a **three year period of** no mining and partial reclamation. The drain was constructed by laying perforated pipe in a trench excavated in the pit floor and covering with sandstone. General dip direction was into the final highwall. The drain was extended across each pit and excavated into the underclay to promote positive drainage to the outcrop where mining had begun. When the final high wall was reached, a chimney drain of coarse sandstone spoil was constructed to intercept expected groundwater seepage. The drain was completed in 1991, and continues to discharge as of this writing.

Final reclamation plans also included the construction of a three foot thick clay cap over the graded spoil fill. The cap was built from subsoil and was to have a saturated permeability of 2 x 10^{-6} cm/sec. Maximum dry density was 110 lbs/ ft^3 with an optimum moisture content of 17 %. The cap was constructed in lifts and compacted with a sheepsfoot roller. However, it was difficult to maintain optimum moisture content for maximum compaction and the clay was prone to cracking when dry. Final grading was shaped to promote runoff from the mined area

Median water quality of the drain during and after mining is summarized in table 5. Net alkalinity increased eight fold, and sulfate concentrations declined about 40 percent in the highwall drain after reclamation was complete. Manganese concentrations declined slightly. The highwall drain has produced alkaline water for six years after reclamation, although sulfate concentrations remain somewhat elevated. Analysis of the active mining spoil seep is indicative of the very acid waters that could have developed from this mine. Average discharge from the drain is about 8.7 gpm for a 30 acre mined area.

Table 5
Summary Water Quality, Rapchak Mine

Monitor Point	pH (S U)	Net Alkalinity (mg/l $CaCO_3$ Eq.)	T. Iron (mg/l)	T. Manganese (mg/l)	T. Aluminum (mg/l)	Sulfate (mg/l)
Highwall Drain, Mining	6.3	43	7.25	26.2	5.6	1215
Highwall Drain, After Backfilling	6.9	320	6.6	18.0	0.3	756
Spoil Seep, Mining	2.5	-7400	>300	>300	>500	13200

The effectiveness of the clay barrier and special handling is difficult to quantify. Elevated sulfate concentrations indicate that some oxidation and leaching is occurring. However, as shown in figure 3, alkalinity increased, and sulfate decreased as backfilling, capping and reclamation was completed. A seasonal effect on both parameters is also seen in figure 3. Alkalinity is at minimum in the spring, a period of major recharge. At the same time, sulfate concentrations peak, possibly indicating a flushing of accumulated oxidation products. Water quality conditions and response to seasonal precipitation patterns suggest the water management practices, clay barrier, and special handling **reduced, but did** not eliminate, recharge and leaching.

The Spaw mine included a lowwall left as barrier between the mine and a nearby stream. A saturated zone about 20 feet thick developed behind the lowwall, contacting acid rock in the fill. The lowwall is acting like a leaky dam, discharging acid ground water. Pit floor drains or other hydrologic routing could have been used to prevent acid drainage.

Alkaline Addition

All of the mines in this study utilized some level of alkaline supplement, with limestone or lime products added to the pit floor and spoil fill. Application rates ranged from 100 to 300 tons per acre. Results are typified by the Rapchak site where lime dust was applied to the pit floor, ten feet above the pit floor, and at the regraded spoil surface.

The Rapchak mine contained no significant carbonate material in the overburden (NP=5.35 tons/1000tons). Spoil water was initially very acid (table 5), but turned alkaline as liming materials were added during backfilling and reclamation as shown in figure 3. Alkaline addition was effective in supplying alkalinity to ground water on a site that otherwise contained very little carbonate material.

Brady and others (1990), found mixed results on 10 Pennsylvania mine sites with alkaline addition. Sites which were successful in preventing or ameliorating acid drainage had several common factors. These included high application rates of alkaline materials, special handling of pyritic materials, and timely backfilling.

Rose et al.(1 995) reported the results of an ongoing alkaline addition project in Clearfield county, Pennsylvania. Baghouse lime was added at rates from 150 to 1080 tons/acre, calculated from ABA data. Preliminary results show alkaline groundwater with low metals concentrations. This same mine includes some test cells constructed of high sulfur materials, subjected to various alkaline addition treatments. Even cells with high alkaline addition rates unexpectedly produced acid leachates. Rose et al. (1995) observed that the pyritic material was exposed to weathering for an extended period before construction of the test cells. Acid generation had begun even before the cells were completed. Rapid application of alkaline material and timely backfilling might have alleviated acid generation.

Smith and Brady (1998) emphasize the importance of thorough incorporation into the backfill, placement with special handled acid material, and adding material of sufficient quantity and quality.

Alkaline import from a nearby mine with excess alkaline material was successful in preventing acid drainage on a West Virginia mine site (Skousen and Larew, 1994). Although the amount needed calculated from ABA data equaled about one foot of alkaline shale, the operator actually imported about three times this amount.

SUMMARY AND CONCLUSIONS

Special Handling Special handling of acid forming materials on six Pennsylvania surface coal mine sites yielded mixed results. Site specific geology and geochemistry (the rocks), surface and ground water hydrology (the water) and mining practices largely control the quality and quantity of post mine drainage. Mining technology and techniques provide some means to offset or modify unfavorable geologic and hydrologic conditions via water management, dry placement, alkaline addition or other amendments. The techniques are most useful in a process of site evaluation, plan design and implementation.

Postmining metals concentrations, in particular manganese, were not totally controlled by special handling techniques, but are also influenced by mineral residence, pH and reduction/oxidation potential. Cravotta et.al. (1994) found that metals concentration in spoil ground water at a Pennsylvania mine were not significantly affected by a change to special handling.

Special handling effectiveness may be limited by the quantity of potentially acid rock on site. Most mines contained only small quantities of potentially acid forming rock, generally no more than 5 to 10 percent of the overburden. Yet, if improperly handled, acid drainage sometimes resulted.

Water Management: Water management techniques such as pit floor and highwall drains help prevent the buildup of a spoil ground water table and quickly convey intercepted water out of the mined area. Rapchak and Highwoods mines both used drains in the spoil to manage and discharge ground water, in combination with alkaline addition. The retention of a lowwall at another mine site in Pennsylvania raised the water table in spoil to contact acid rock, where the original handling plan was dry placement.

Effectiveness of clay barriers were difficult to assess. The Rapchak mine continues to discharge ground water in appreciable quantity, even though a clay barrier was placed over the regraded spoil.

Alkaline Addition: Alkaline addition was beneficial in producing aqueous alkalinity, if placement was in the ground water flow path and the amounts of material were large. A special handling and alkaline addition site in Pennsylvania is producing alkaline ground water where amended, and extremely acid water in non-amended test cells (Rose et.al.1995). Alkaline addition rates are large and the material is incorporated into the backfill. Alkaline addition incorporated into a West Virginia spoil backfill reduced acid load by 40 to 50 percent (Meek, 1994)

Operating Techniques: Mining rapidly to completion and without delay generally resulted in better postmining water quality conditions. Green Phase 2 and Rapchak experienced significant delays or cessations before mining was complete. Green Phase 2 ultimately produced add drainage. Acid drainage was avoided at Rapchak mine by implementation of a rigorous handling and placement plan and large alkaline addition rates. Final backfilling at Rapchak brought rapid improvement in water quality (figure 3). In contrast, Schott, Highwoods and Green Phase 1 were mined without work stoppage and produced alkaline drainage. The Schott and Highwoods mines especially were open only for short periods of time with reclamation closely following mining.

Mine drainage quality is controlled by geologic, hydrologic and mining conditions. Recognition of mine site conditions, designing a site specific plan, and implementing it will maximize effectiveness of special handling operations. A combination of water management , alkaline addition and special handling methods seems most useful for controlling hydrologic impacts, but may not totally prevent them in all cases.

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